BIOLOGICAL MONITORING REPORT FOR NL INDUSTRIES SUPERFUND SITE IN PEDRICKTOWN, NEW JERSEY – YEAR 2004

-- Volume I --

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SUMMARY

This report presents the results of the fourth year (Year 2004) of a biological monitoring program for the NL Industries Superfund Site in Pedricktown, New Jersey. The monitoring effort occurred during the period of September 20 - 22, 2004, according to an experimental design outlined in a monitoring plan, as well as subsequent documents and understandings, approved by Region 2, U. S. Environmental Protection Agency (U. S. EPA).

The objectives of the monitoring program are to document environmental characteristics of the NL Site after remediation of the site, which included dredging of parts of the aquatic system at the site. The initial monitoring study, which was conducted in the summer of 2000, constituted a pre-remediation evaluation of the site. Post-remediation evaluations of the site occurred in 2002, 2003, and 2004 (this study).

Monitoring in 2004 (and in previous years) was conducted at 10 potentially impacted sampling stations: five stations in the West Stream, as well as five downstream stations located in a channel maintained by the U. S. Army Corps of Engineers (COE). Monitoring also occurred at two reference stations: one station in a streamlet discharging to the West Stream and the other in Oldmans Creek.

Dissolved lead concentrations in surface water at potentially impacted stations ranged from <0.0050 to 0.017 mg/L, as compared to <0.0050 mg/L at the reference stations. Lead levels in surface sediment (approximately 0 – 15 cm in depth) at potentially impacted stations ranged from 20 to 1,400 mg/kg (dry wt) vs. 24 to 62 mg/kg in reference sediment.

Body burdens of lead in aquatic life (a total of 10 different species) collected from potentially impacted stations ranged from <0.12 to 4.2 mg/kg (wet wt) vs. 0.16 to 0.26 mg/kg at reference stations. Lead concentrations in surface water, surface sediment, and aquatic life at potentially impacted stations displayed the same basic upstream-to-downstream downward trend.

Macrobenthos indigenous to most potentially impacted stations and the Oldmans Creek reference station were characterized by Lloyd-Ghelardi equitability indices ("e") that ranged from 0.22 to 0.54. These values suggest some biological degradation at these stations since "e" values less than about 0.6 are often considered characteristic of polluted waters. In contrast, "e" values for two upstream stations and for the nearest reference station (the streamlet that discharges to the West Stream) ranged from 0.95 to 1.12.

Three-phased laboratory toxicity tests were conducted with surface sediment in which sediment not judged to be toxic in initial tests was evaluated by progressively more rigorous tests. Phase I toxicity tests – 10-day tests with amphipods (*Hyalella azteca*) – demonstrated that sediment from all potentially impacted stations was no more toxic from a statistical perspective than sediment from a nearby and ecologically similar reference station.

Phase II toxicity tests – 10-day tests with midges (*Chironomus tentans*) – identified only a single site station as being characterized by sediment that was more acutely toxic than sediment from the West Stream reference

station. Additionally, just growth (weight) of midges exposed to this sediment, not survival of organisms, was impaired.

Finally, Phase III toxicity tests – chronic (42-day) tests with amphipods – documented sediment from several site stations to be more toxic in terms of survival and/or growth (weight) than sediment from the West Stream reference station after 28 days of exposure to sediment. However, at 42 days of exposure to sediment, these toxicological differences were no longer evident except for weight of amphipods exposed to sediment from one site station. In addition, reproduction of amphipods at 35 and 42 days of exposure to site sediment was never less than reproduction of organisms exposed to sediment from the West Stream reference station.

The coefficient of determination (r^2) between various toxicological responses of organisms exposed to sediment and concentration of lead in sediment is relatively low – 28% for survival of amphipods in acute tests; 11% for weight of midges in acute tests; and 8% for weight of amphipods after 42-days of exposure to sediment in chronic tests. These percentages represent the amount of variation in toxicological response of organisms that can be explained in terms of variation in lead concentration of sediment.

Wildlife food-web models, based on body-burdens of lead in aquatic life, but also including lead exposure from water and sediment, were developed for a piscivorous bird (the belted kingfisher, *Megaceryle alcyon*) and a piscivorous mammal (the mink, *Mustela vison*). The food-web model for the belted kingfisher generated the following hazard quotients (HQs) for selected segments in the study area: 7.5 (upstream stretch of West Stream); 1.0 (ponded area south of COE channel); 1.4 (COE channel); and 1.0 (West Stream and Oldmans Creek reference areas collectively considered).

The food-web model for mink generated HQs of: 17 (upstream stretch of West Stream); 2.3 (ponded area south of COE channel); 3.1 (COE channel); and 2.2 (West Stream and Oldmans Creek reference areas). In both the belted kingfisher and mink models, water was an inconsequential contributor of lead. In addition, sediment (not prey) was the dominant exposure route.

Time-series comparisons of environmental characteristics at the NL Site documented the mean concentration of lead in surface sediment at potentially impacted stations as having decreased from 379 mg/kg (dry wt) in 2000 to 296 mg/kg in 2004 (a 22% decrease).

Body burdens of lead in aquatic life collected from potentially impacted stations decreased from a mean value of 1.8 mg/kg (wet wt) in 2000 to <0.63 mg/kg in 2004.

The macrobenthos community at potentially impacted stations (as judged by the Lloyd-Ghelardi Equitability Index) remained relatively constant over the years ("e" = 0.52 – 0.66).

Phase I toxicity tests (evaluation of acute toxicity of sediment to amphipods) identified 70% of sediments (stations) to be toxic in 2000, while 0% were so identified in 2004. Phase II testing (assessment of acute toxicity of sediment to midges) demonstrated a reduction in toxicity from 67% to 10% during the 4-year period. Finally, Phase III toxicity testing (evaluation of chronic toxicity of sediment to amphipods) documented just a single station in 2004 that was associated with toxicity at the end of the 42-day testing period.

Finally, modeled HQs for lead in both the belted kingfisher and mink continued on a downward trend in 2004.

1. INTRODUCTION

The results of the fourth year (Year 2004) of a biological monitoring program for the NL Industries Superfund Site in Pedricktown, New Jersey, are presented in this report. The monitoring effort occurred during the period of September 20 – 22, 2004. The monitoring program was performed according to an experimental design outlined in a monitoring plan (CDR Environmental Specialists, 2000), as well as subsequent documents and understandings, approved by Region 2, U. S. Environmental Protection Agency (e. g., U. S. EPA, 2000a).

Monitoring was conducted at 10 potentially impacted (PI) sampling stations (Figure 1). Five of these potentially impacted stations (Stations 1 through 5) are located in a small, sometimes intermittent, lotic system termed the West Stream. One of these stations (Station 1) is situated adjacent to the upstream boundary of the site. Another five potentially impacted stations (Stations 6 through 10) are situated downstream from the West Stream in a channel maintained by the U. S. Army Corps of Engineers (COE). This channel discharges to the Delaware River and is characterized by tidal fluctuations.

Two reference stations were also evaluated in the monitoring study. One of these reference stations is located in a streamlet that discharges to the West Stream, while the other station is situated in Oldmans Creek. Oldmans Creek is a tidally influenced aquatic system that discharges to the Delaware River about 3 km (2 miles) upstream of the mouth of the COE channel. Photographs of the 10 potentially impacted sampling stations and the two reference stations are presented in Appendix A of this document.

This report consists of two volumes. This volume (Volume I) presents the most relevant information generated in the 2004 biological monitoring study. Volume II contains the laboratory reports, including quality control (QC) data, which constitute the basis of Volume I.

2. PROCEDURES

Surface water at each of the 10 potentially impacted sampling stations and two reference stations in the study area was monitored at the time of ebb tide for eight physical and chemical variables. Several of these variables – temperature, pH, salinity, and specific conductance – were measured in the field with a YSI meter. In addition, water samples were collected directly into appropriate sampling containers provided by the chemistry laboratory (STL Mobile), placed in coolers containing ice, and transported by overnight courier to the laboratory. At the laboratory, the samples were analyzed for hardness (EPA Method SM2340B), total suspended solids (EPA Method 160.2), total lead (EPA Method 6010B), and dissolved lead (EPA Method 6010).

Surface sediment (down to a depth of about 15 cm) was collected at all 12 stations with an Ekman grab sampler. Sediment samples were transferred to appropriate sampling containers provided by the chemistry laboratory, placed in coolers with ice, and transported by overnight courier to the laboratory. At the laboratory, the samples were analyzed for grain-size distribution (ASTM Method D422), total organic content (EPA Method 9060), pH (EPA Method 9045), and lead (EPA Method 6010B).

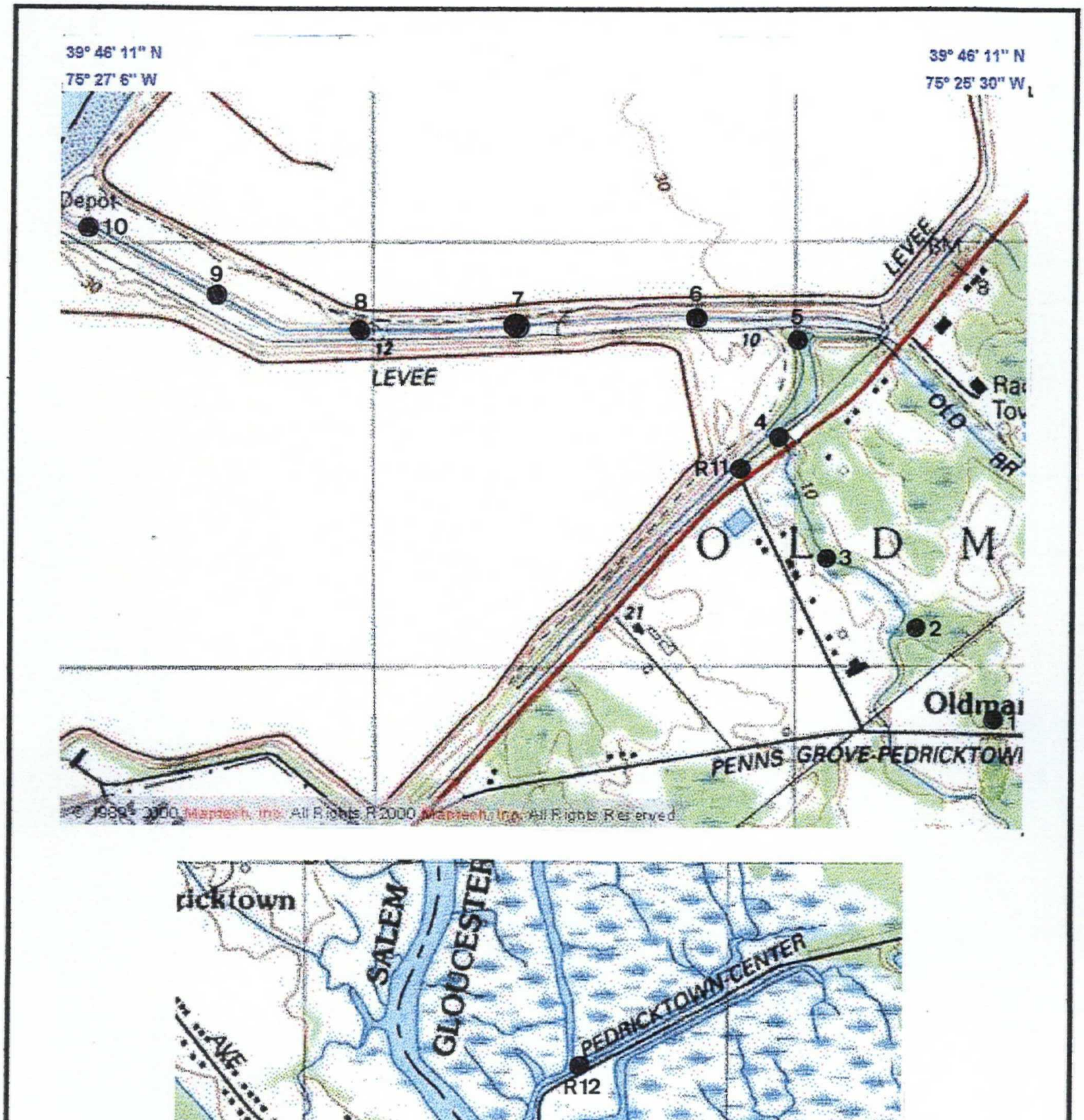

Figure 1.__Locations of sampling stations in study area. Ten (10) potentially impacted stations located in the West Stream (Stations 1 - 5) and COE channel (Stations 6 - 10), as well as one reference station (R 11) situated in a streamlet to the West Stream, are illustrated in the upper map. A second reference station (R 12), located in Oldmans Creek, is illustrated in the bottom map.

Aquatic life (primarily finfishes, but also crayfish) was collected by baited minnow traps at 9 of the 10 potentially impacted stations (Stations 2 - 10) and at both reference stations. The organisms were enumerated and measured for length in the field, often composited (within station and species), placed in appropriate plastic bags provided by the chemistry laboratory, and transported in coolers with ice by overnight courier to the chemistry laboratory. At the laboratory, whole bodies of organisms were analyzed for total solids content (EPA Method 160.3) and body burdens of lead (EPA Method 6010B).

Macrobenthos were collected at all 12 stations except with an Ekman grab sampler. Three replicate sediment samples were collected at each station. The samples were washed through a U. S. Standard No. 30 sieve (0.595-mm mesh), preserved in 10% formalin, and shipped to the taxonomy laboratory (Barry A. Vittor and Associates). At the laboratory, the samples were placed in 70% isopropyl alcohol and dyed with rose-bengal stain. The samples were then numerically identified to the lowest practical taxon and characterized for various community characteristics.

Toxicity of surface sediment was evaluated at all 12 stations by a phased approach. (The aquatic toxicology laboratory was the SeaCrest Group.) In Phase I, toxicity of sediment from all 12 stations was evaluated in acute (10-day) tests with amphipods (*Hyalella azteca*) according to protocols for EPA Test Method 100.1 (U. S. EPA, 2000b). None of the 10 site sediments were determined to be acutely toxic. Consequently, sediment from all 10 potentially impacted stations required additional (more definitive) testing for toxicity.

In Phase II of the toxicological testing, sediment from the 10 potentially impacted stations, which were determined to be nontoxic in the above-discussed amphipod tests (and reference sediments), was evaluated in acute (10-day) tests with midges (*Chironomus tentans*). (The initial protocol for these tests was to extend the 10-day exposure time identified for EPA Test Method 100.2 (U. S. EPA, 2000b) to 14 days. However, previous testing of sediment from the study area had employed the standard EPA procedures and, for comparative purposes, it was judged appropriate to conclude the tests according to the standard 10-day exposure period.) This series of tests identified none of the 10 site sediments to be acutely toxic, with the exception of a single station at which just growth (weight) of midges, not survival of organisms, was affected. Consequently, sediment from all 10 site stations was tested further for toxicity.

In Phase III of the toxicological testing, sediment from the 10 potentially impacted stations and reference sediments was evaluated in chronic (42-day) tests with amphipods according to protocols for EPA Test Method 100.4 (U. S. EPA, 2000b).

Wildlife food-web models and associated hazard quotients (HQs) were developed for a piscivorous bird (the belted kingfisher, *Megaceryle alcyon*) and a piscivorous mammal (the mink, *Mustela vison*) potentially exposed to lead in selected locations of the study area. Lead concentrations measured in surface water, surface sediment, and aquatic life (assumed prey of wildlife) from the study area were employed as input to the models.

3. MAJOR RESULTS

This part of the report consists of three sections addressing chemical characteristics of environmental media, macrobenthos characteristics, and sediment toxicity.

3.1 Chemical Characteristics of Environmental Media

Chemical characteristics of surface water and surface sediment are addressed, followed by evaluation of body burdens of lead in aquatic life.

3.1.1 Surface Water

Temperature of surface water during the time of the study ranged from about 15 to 19 ^{0}C (Table 1). Values of pH ranged between 6.2 and 7.5. Salinity, conductivity, and hardness were, as expected, positively correlated. Total suspended solids at the sampling stations ranged from 7.0 to 36 mg/L.

Total lead concentrations at potentially impacted stations ranged from <0.0050 at downstream stations to 0.036 mg/L at the most upstream station (Station 1), as compared to <0.0050 mg/L at the reference stations. Concentrations of dissolved lead exhibited the same basic pattern, with the highest level being 0.017 mg/L at Station 1. This tendency for lead concentrations in the West Stream to be higher than concentrations in the COE channel may be confounded by inflowing tidal waters from the Delaware River, which may have "diluted" lead concentrations in the COE channel.

3.1.2 Surface Sediment

Silt and clay content of surface sediment varied substantially from 8% at Sampling Station 6 to 79% at Station 12 (Table 2). Total organic content (TOC) of sediment, which was positively correlated with silt /clay content, varied by about two orders-of-magnitude, from 0.44% at Station 6 to 28% at Station 3. The pH of sediment varied from 6.2 to 7.0.

Lead concentrations in surface sediment at potentially impacted stations ranged from 20 to 1,400 mg/kg (dry wt) vs. 24 to 62 mg/kg in reference sediment. Lead levels in sediment at potentially impacted stations exhibited the same basic upstream-to-downstream downward trend observed for lead levels in surface water.

Sedimentary lead concentrations presented in this volume of the report are described on a "wet weight" basis, as well as on the conventional "dry weight" basis, in order to facilitate food-web modeling for wildlife.

3.1.3 Body Burdens of Lead in Aquatic Life

Nine species of finfishes and crayfish were collected during the study (Table 3). These organisms were captured at both reference stations and at all potentially impacted sampling stations except Station 1, which was characterized by a limited amount of surface water. There was no single species of aquatic life that was obtained at all sampling stations.

Lead concentrations in whole bodies of aquatic life collected from potentially impacted stations ranged from <0.12 to 4.2 mg/kg (wet wt), with the maximum concentration (4.2 mg/kg) occurring in crayfish from Station 2 in the Western Stream. Lead levels in aquatic life at potentially impacted stations displayed the same basic upstream-to-downstream downward trend as lead levels noted for surface water and surface sediment. Fishes obtained from the reference stations exhibited lead body burdens of from 0.16 to 0.26 mg/kg.

3.2 Macrobenthos Characteristics

Total number of macroinvertebrate taxa observed at the potentially impacted sampling stations ranged from seven taxa at Station 1 in the West Stream, and Station 8 in the COE channel, to 25 taxa at Station 5 in the ponded area south of the COE channel (Table 4). Total number of taxa observed at reference stations

Table 1.__Physical and chemical characteristics of surface water in study area[a]

Sampling station (tidal conditions)	Temperature (°C)	pH (pH units)	Salinity (ppt)	Specific conductance (uS/cm)	Hardness (mg/L)	Total suspended solids (mg/L)	Lead (mg/L)	
							Total	Dissolved
				Potentially impacted stations[b]				
1 (nontidal)	15.7	6.5	0.1	192	64	36	0.036	0.017
2 (nontidal)	16.0	6.2	0.3	578	84	21	0.027	0.012
3 (nontidal)	16.6	6.5	0.3	366	100	8.0	0.013	0.0052
4 (nontidal)	17.4	6.6	0.2	398	130	9.0	0.0083	<0.0050
5 (ebb)	17.4	6.4	0.2	381	140	9.0	<0.0050	<0.0050
6 (ebb)	17.3	6.5	0.2	367	130	13	<0.0050	<0.0050
7 (ebb)	17.7	6.9	0.2	341	120	7.0	<0.0050	<0.0050
8 (ebb)	17.9	7.4	0.2	318	110	22	<0.0050	<0.0050
9 (ebb)	18.0	7.5	0.1	244	79	16	<0.0050	<0.0050
10 (ebb)	18.7	7.1	0.1	231	74	19	<0.0050	<0.0050
				Reference Stations				
11c (ebb)	15.5	6.9	0.3	533	180	21	<0.0050	<0.0050
12[d] (ebb)	17.6	7.2	0.1	209	65	19	<0.0050	<0.0050

Table 1.__Continued

[a]Surface water was measured or collected on September 20, 2004. Field measurements were made for temperature, pH, salinity, and conductivity, while hardness, total suspended solids, and lead were evaluated in the laboratory.

[b]Potentially impacted sampling stations are sequentially numbered from the most upstream station (Station 1 in the West Stream) to the most downstream station (Station 10 in the COE channel).

[c]Reference Station 11 is located west of Route 130 in a streamlet that discharges to the West Stream.

[d]Reference Station 12 is located in Oldmans Creek.

Table 2.__Physical and chemical characteristics of surface sediment in study area[a]

Sampling station	Silt and clay (%, dry wt)	Total organic content (%, dry wt)	pH (pH units)	Lead (mg/kg) Wet wt	Lead (mg/kg) Dry wt
		Potentially impacted stations[b]			
1	48	5.8	6.4	310	1,400
2	72	18	6.7	130	860
3	39	28	5.8	31	180
4	28	13	6.2	95	190
5	11	2.9	6.7	20	73
6	8	0.44	6.7	19	31
7	17	1.2	6.5	40	98
8	8.6	0.45	7.0	15	20
9	62	4.4	6.2	32	81
10	24	0.75	6.4	19	27
		Reference stations			
11[c]	29	2.4	6.6	8.6	24
12[d]	79	3.8	6.2	25	62

[a]Surface sediment (down to a depth of about 15 cm) was collected with a Ekman grab sampler on September 20 - 21, 2004.

[b]Potentially impacted sampling stations are sequentially numbered from the most upstream station (Station 1 in the West Stream) to the most downstream station (Station 10 in the COE channel).

[c]Reference Station 11 is located west of Route 130 in a streamlet that discharges to the West Stream.

[d]Reference Station 12 is located in Oldmans Creek.

Table 3.__Body burdens of lead in aquatic life in study area[a]

Sampling station	Species of aquatic life	Number of organisms in evaluated sample	Total length (mm)	Total solids content (% wet)	Lead body burden (mg/kg, wet wt)
	Potentially Impacted Stations[b]				
2	Eastern mudminnow (*Umbra pygmaea*)	6	45 - 85	24	1.1
	Redfin pickeral (*Esox americanus*)	1	135	23	1.2
	Crayfish	8	30 - 55	22	4.2
3	Eastern mudminnow	2	60 - 65	24	1.2
	Bluespotted sunfish (*Enneacanthus gloriosus*)	7	55 - 65	27	1.1
	Crayfish	1	50	18	1.3
4	Pumpkinseed (*Lepomis gibbosus*)	3	80 - 120	38	0.38
	Brown bullhead (*Ictalurus nebulosus*)	1	7	21	0.99
	Crayfish	2	45 - 90	26	0.78
5	Bluespotted sunfish	2	55 - 60	27	0.16
	Bluegill (*Lepomis macrochirus*)	9	40 - 50	26	0.16
6	Pumpkinseed	2	110 - 115	29	0.52
	Crayfish	1	70	19	0.32
7	Redfin pickeral	2	95 - 110	22	0.11
	Bluespotted sunfish	6	60 - 75	27	0.16
	Pumpkinseed	1	80	29	<0.14
	Brown bullhead	2	135 - 155	22	0.18
	Crayfish	2	40 - 45	22	0.97
8	Redfin pickeral	1	115	22	0.48
	Crayfish	8	35 - 50	21	0.21
9	Bluespotted sunfish	2	70 - 75	28	0.23
	Pumpkinseed	1	~80	27	0.19
10	Pumpkinseed	1	70	29	<0.14
	Shinner (*Notropis* sp.)	3	60 - 70	23	<0.12
	Reference Stations				
11[c]	Eastern mudminnow	1	90	24	0.26
	Bluespotted sunfish	1	65	28	0.16
12[d]	Mummichog (*Fundulus heteroclitus*)	18	60 - 80	26	0.20
	White perch (*Morone americana*)	4	65 - 70	24	0.23

[a]Aquatic life was collected with baited minnow traps during the period of September 20 - 22, 2004.

[b]Potentially impacted sampling stations are sequentially numbered from the most upstream station (Station 1 in the West Stream) to the most downstream station (Station 10 in the COE channel).

[c]Reference Station 11 is located west of Route 130 in a streamlet that discharges to the West Stream.

[d]Reference Station 12 is located in Oldmans Creek.

Table 4.__Selected community characteristics of macrobenthos in study area[a]

Sampling station	Total number of taxa	Total number of individuals	Mean density of individuals (no./m^2)	Shannon-Weaver diversity index (H)	Lloyd-Ghelardi equitability index (e)	Major taxa – % of total taxa (Arthropoda = Ar; Annelida = An; Mollusca = M; Plathyhelminthes = P)
			Potentially Impacted Stations[b]			
1	7	22	318.7	0.75	1.12	Ar = 86%; M = 14%
2	10	66	956.7	0.83	0.95	Ar = 100%
3	19	304	4,406.0	0.53	0.24	Ar = 68%; An = 26%; M = 5%
4	22	193	2,797.3	0.88	0.49	Ar = 73%; An = 14%; M = 9%; P = 4%
5	25	461	6,681.0	0.85	0.40	Ar = 60%; An = 12%; M = 24%; P = 4%
6	10	390	5,652.0	0.59	0.54	Ar = 50%; An = 40%; M =12%; P = 10%
7	15	436	6,318.7	0.38	0.22	Ar = 73%; An = 20%; M = 7%
8	7	145	2,101.7	0.34	0.41	Ar = 43%; An = 43%; M = 14%
9	11	2,098	30,406.0	0.46	0.35	Ar = 64% An = 36%
10	22	1,264	18,319.0	0.89	0.50	Ar = 64%; An = 14%; M = 23%
			Reference stations			
11[c]	7	170	2,463.7	0.68	0.95	Ar = 43%; An = 43%; M = 14%
12[d]	13	215	3,116.0	0.51	0.34	Ar = 46%; An = 23%; M = 31%

[a]Macrobenthos were collected with a Ekman grab sampler (down to a sediment depth of about 15 cm) on September 20 - 21, 2004. Three replicate sediment samples were collected at each sampling station.

[b]Potentially impacted sampling stations are sequentially numbered from the most upstream station (Station 1 in the West Stream) to the most downstream station (Station 10 in the COE channel).

[c]Reference Station 11 is located west of Route 130 in a streamlet that discharges to the West Stream.

[d]Reference Station 12 is located in Oldmans Creek.

ranged from 7 to 13. Total number of individuals and mean density of individuals generally exhibited a positive (but imperfect) correlation with total number of taxa.

Macrobenthos at all potentially impacted stations and at the two reference stations were characterized by Shannon-Weaver diversity indices ("H") that ranged from 0.34 at Station 8 to 0.89 at Station 10. All of these values suggest moderate to extreme degradation of the whole aquatic system since "H" is generally between 3 and 4 in unpolluted waters (U. S. EPA, 1973).

Lloyd-Ghelardi equitability index ("e") for potentially impacted stations ranged from 0.40 to 0.95 (excluding an artifact of 1.12 for Station 1) vs. 0.34 to 0.95 for reference stations. These values suggest some degradation at all stations except at Potentially Impacted Station 2 and Reference Station 11 (where the 0.95 values was recorded) since "e" values less than about 0.6 are often considered characteristic of polluted waters (U. S. EPA, 1973).

3.3 Sediment Toxicity (Phased Toxicity Testing)

Results of the three phases of toxicity testing are sequentially presented.

3.3.1 Phase I (Acute Amphipod Tests)

Acute (10-day) toxicity tests with amphipods, which were conducted with surface sediment from all 12 sampling stations, were judged to have been successfully conducted primarily because mean survival of control organisms was 87.5% (Table 5), thereby conforming with test criteria of at least 80%. In addition, the mean weight of control organisms was 0.13 mg (dry wt) vs. 0.11 mg at start of the tests (Volume II of report).

Amphipod tests demonstrated that sediment from all potentially impacted stations was no more toxic from a statistical perspective than sediment from the West Stream reference station (Station 11), which is the reference station nearest to the NL Site and more similar in ecological characteristics than the other reference station in Oldmans Creek (Station 12).

This conclusion is based on statistical protocols (Table 5) in which a parametric analysis of variance (ANOVA) identified "over-all" statistically significant differences in survival of amphipods exposed to the 12 sediments (Element 3 of Table 5). Tukey's (w) test then indicated that, although survival for many stations was significantly different, survival for all potentially impacted stations was either greater than or similar to survival for Reference Station 11. Growth (weight) of amphipods exposed to sediment from the 12 stations displayed the same basic pattern as described for survival (Element 4 of Table 5).

The coefficient of determination (r^2) between survival of amphipods (Table 5) and concentration of lead in sediment (Table 3) is 0.28. Alternatively stated, only 28% of variation in survival of amphipods can be explained in terms of variation in lead concentration of sediment.

3.3.2 Phase II (Acute Midge Tests)

Results of the above-described acute toxicity tests with amphipods indicated that sediment from all potentially impacted sampling stations required additional (more definitive) testing for toxicity.

This additional testing, which consisted of acute (10-day) toxicity tests with midges, was judged to have been successfully conducted primarily because control organisms conformed with test criteria of at least 70%

Table 5.__Statistical analysis of survival and growth (weight)of amphipods (*Hyalella azteca) exposed for* 10 days to laboratory control sediment and surface sediment from study area (Phase I toxicity tests)[a]

1. Number of surviving amphipods (mean weight: mg, dry wt)[b]

Sediment source (S)	Replicate – r: 1	2	3	4	5	6	7	8	Mean ($\bar{x}$)	Variance (s^2)
Control	8 (0.13)	10 (0.09)	8 (0.11)	9 (0.14)	8 (0.17)	7 (0.16)	10 (0.09)	10 (0.12)	8.75 (0.1262)	1.36 (0.0009)
Potentially impacted (PI) stations										
1	4 (0.08)	0 (–)	0 (–)	1 (0.01)	1 (0.03)	0 (–)	0 (–)	0 (–)	0.75 (0.0400)	1.93 (0.0013)
2	3 (0.10)	4 (0.08)	0 (–)	0 (–)	2 (0.15)	1 (0.10)	0 (–)	3 (0.17)	1.62 (0.1200)	2.55 (0.0014)
3	6 (0.13	6 (0.12)	4 (0.15)	5 (0.08)	6 (0.05)	4 (0.07)	6 (0.12)	4 (0.07)	5.12 (0.0988)	0.98 (0.0013)
4	1 (0.10)	0 (–)	5 (0.13)	1 (0.10)	4 (0.05)	3 (0.10)	1 (0.02)	2 (0.05)	2.12 (0.0786)	2.98 (0.0015)
5	2 (0.20)	3 (0.10)	3 (0.13)	3 (0.13)	2 (0.15)	4 (0.07)	2 (0.10)	3 (0.13)	2.75 (0.1262)	0.50 (0.0015)
6	9 (0.13)	7 (0.11)	5 (0.08)	6 (0.08)	7 (0.07)	5 (0.12)	7 (0.06)	6 (0.13)	6.50 (0.0975)	1.71 (0.0008)
7	7 (0.13)	6 (0.10)	6 (0.08)	4 (0.07)	3 (0.10)	6 (0.08)	5 (0.10)	3 (0.17)	5.00 (0.1038)	2.29 (0.0011)
8	2 (0.05)	3 (0.10)	6 (0.05)	6 (0.03)	2 (0.05)	2 (0.05)	0 (–)	6 (0.07)	3.38 (0.0571)	5.41 (0.0005)
9	6 (0.12)	9 (0.08)	8 (0.06)	5 (0.14)	7 (0.06)	6 (0.10)	10 (0.12)	8 (0.08)	7.38 (0.0950)	2.84 (0.0009)
10	2 (0.10)	3 (0.13)	5 (0.10)	4 (0.25)	2 (0.05)	6 (0.12)	1 (0.10)	2 (0.15)	3.12 (0.1250)	2.98 (0.0034)
Reference (R) stations										
11	0 (–)	1 (0.02)	2 (0.05)	1 (0.06)	2 (0.07)	3 (0.10)	0 (–)	2 (0.05)	1.38 (0.0583)	1.12 (0.0007)
12	10 (0.12)	8 (0.10)	7 (0.13)	8 (0.16)	6 (0.12)	6 (0.08)	7 (0.11)	8 (0.17)	7.5 (0.1238)	1.71 (0.0009)

2. Cochran's (C) test for homogeneity of variances of amphipod data

$C_{(cal.)} = s^2\,(max.) / s^2\,(total)$

Survival data[c]

$C_{(cal.)} = 5.41 / 28.36 = 0.19$ ns, as compared to $C_{(tab.)} = 0.22$ for $P = 0.05$, $k = 13$, and $v = 7$

Weight data[c]

$C_{(cal.)} = 0.0034 / 0.0162 = 0.21$ ns, as compared to $C_{(tab.)} = \sim 0.23$ for $P = 0.05$, $k = 13$, and $v = \sim 6$

3. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of amphipod survival[d, e]

Source of variation in survival	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	665.37	55.45	25.44 **
Error (R)	s (r - 1) = 91	198.62	2.18	
Total (T)	sr - 1 = 103	863.99		

as compared to $F_{(tab.)} = 2.42$ for $P = 0.01$, 12 numerator df, and 91 denominator df

Sediment source (S):	PI 1	R 11	PI 2	PI 4	PI 5	PI 10	PI 8
Mean ($\bar{x}$) number of survivors:	0.75	1.38	1.62	2.12	2.75	3.12	3.38

Sediment source (S):	PI 7	PI 3	PI 6	PI 9	R 12	Control
Mean ($\bar{x}$) number of survivors:	5.00	5.12	6.50	7.38	7.50	8.75

$w_{(P = 0.05)} = q$ (square root of error MS / r) $= 4.83$ (square root of 2.18 / 8) $= 0.89$

Table 5.__Continued

4. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of amphipod weight[d, e]

Source of variation in weight	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	0.0602	0.0050	4.17 **
Error (R)	s (r - 1) = 79	0.0987	0.0012	
Total (T)	sr - 1 = 91	0.1589		as compared to $F_{(tab.)}$ = 2.45 for P = 0.01, 12 numerator df, and 79 denominator df

Sediment source (S):	PI 1	PI 8	R 11	PI 4	PI 9	PI 6	PI 3
Mean (x) weight:	0.0400	0.0571	0.0583	0.0786	0.0950	0.0975	0.0988

Sediment source (S):	PI 7	PI 2	R 12	PI 10	PI 5	Control
Mean (x) weight:	0.1038	0.1200	0.1238	0.1250	0.1262	0.1262

$w_{(P = 0.05)}$ = q (square root of error MS / r)
= 4.85 (square root of 0.0012 / ~7)
= 0.0240

[a]Surface sediment (down to a depth of about 15 cm) employed in amphipod toxicity tests was collected with a Ekman grab sampler on September 20 - 21, 2004. Laboratory control sediment consisted of clean sand, decaying leaves, and potting soil. Tests were conducted during the period of October 5 - 15, 2004.

[b]Each replicate (r) of a sediment source (S) consisted of 10 amphipods at start of test (i. e., 10 amphipods at end of test = 100% survival).

[c]Cochran's (C) test for amphipod survival and weight indicated homogeneity of variances (as identified by the symbol "ns" for $C_{(cal.)}$). Consequently, further statistical tests were conducted with data by parametric protocols.

[d]Parametric ANOVAs applied to amphipod survival and weight data documented the presence of statistically significant differences among data (as indicated by the symbol " ** " for $F_{(cal.)}$). The specific causes of these significant differences were determined by Tukey's (w) test. In Tukey's test, data underscored by the same horizontal line are not significantly different, whereas data not underscored by the same horizontal line are significantly different.

[e]No sediment from potentially impacted (PI) sampling stations was determined to be more toxic from a statistical perspective than sediment from Reference Station 11. Consequently, sediment from all PI sampling stations (and the reference stations) was further evaluated in "Phase II" acute toxicity tests with another test species (*Chironomus tentans*).

mean survival and a mean weight for surviving organisms of at least 0.48 mg ash-free dry weight. In these tests, mean control survival was 86.3%, and mean weight of survivors was 1.79 mg (Table 6).

The midge tests identified sediment from Reference Station 11 to be more toxic in terms of survival of organisms than sediment from any of the potentially impacted stations (Element 3 of Table 6). In terms of growth (weight) of midges, Potentially Impacted Station 3 was the only site station characterized by sediment in which weight of organisms was significantly less than weight of organisms exposed to sediment from Reference Station 11 (Element 4 in Table 6).

It is important to note that the level of statistical probability (and associated distinctions among stations) identified in Table 6 for survival and weight of midges is only approximate because variances of data sets were characterized by heteroscedasticity in Cochran's (C) test (Element 2 of Table 6). Parametric statistical procedures were nevertheless employed to interpret data rather than nonparametric procedures because Cochran's test indicated only minor heteroscedasticity and because of the limited ability of nonparametric procedures to detect real differences among data.

The coefficient of determination (r^2) between weight of midges (Table 6) and concentration of lead in sediment (Table 3) is 11%. Consequently, only 11% of variation in weight of midges can be explained in terms of variation in lead concentration of sediment.

3.3.3 Phase III (Chronic Amphipod Tests)

Results of the above-described acute toxicity tests with midges indicated that sediment from all potentially impacted sampling stations (including Station 3) merited evaluation by chronic toxicity testing.

This final toxicity testing, which consisted of chronic (42-day) tests with amphipods, was judged to have been successfully performed primarily because mean survival of control organisms was 100% at the end of 28 days of exposure (Table 7), as contrasted to the test criteria of at least 80%.

After 28 days of exposure, amphipods tested with sediment from four site stations (Potentially Impacted Stations 1, 2, 7, and 8) were characterized by survival that was significantly lower than survival of organisms exposed to sediment from Reference Station 11 (Element A.3 of Table 7). Growth (weight) of amphipods exposed for 28 days to sediment from Potentially Impacted Station 3, as well as Potentially Impacted Stations 7 and 8, was significantly less than weight of organisms exposed to sediment from Reference Station 11 (Element A.4 of Table 7).

However, after 42 days of exposure (at the termination of the tests) most of the above-referenced effects were no longer evident. Only weight of amphipods exposed to sediment from Potentially Impacted Station 8 was adversely affected as contrasted to weight of organisms exposed to sediment from Reference Station 11 (Elements B.3 and B.4 of Table 7).

Reproduction of amphipods at 35 and 42 days of exposure to site sediment was never less than reproduction of organisms exposed to sediment from Reference Station 11 (Footnote "b" in Table 7). The coefficient of determination (r^2) between weight of

Table 6.__Statistical analysis of survival and growth (weight) of midges (*Chironomus tentans*) exposed for 10 days to laboratory control sediment and surface sediment from study area (Phase II toxicity tests)[a]

1. Number of surviving midges (ash-free weight; mg, dry wt)[b]

Sediment source (S)	Replicate – r: 1	2	3	4	5	6	7	8	Mean ($\bar{x}$)	Variance (s^2)
Control	8 (1.65)	10 (1.73)	9 (2.24)	9 (0.88)	10 (1.56)	10 (2.06)	6 (1.68)	7 (2.50)	8.63 (1.79)	2.27 (0.24)
Potentially impacted (PI) stations										
1	6 (0.87)	6 (1.07)	6 (0.90)	7 (1.16)	6 (0.93)	7 (0.63)	8 (0.96)	7 (0.76)	6.63 (0.91)	0.55 (0.03)
2	6 (1.00)	8 (0.84)	5 (0.90)	7 (0.76)	10 (0.76)	8 (0.69)	8 (0.77)	7 (0.93)	7.38 (0.83)	2.27 (0.01)
3	10 (0.96)	9 (0.74)	10 (0.81)	10 (0.58)	10 (0.59)	10 (0.58)	10 (0.61)	10 (0.68)	9.88 (0.69)	0.12 (0.02)
4	2 (1.70)	4 (1.10)	3 (1.30)	7 (1.27)	7 (1.17)	9 (1.07)	10 (0.96)	6 (1.12)	6.00 (1.21)	8.00 (0.05)
5	4 (0.65)	5 (1.84)	5 (1.10)	3 (1.03)	4 (1.10)	3 (1.63)	1 (2.10)	3 (1.77)	3.50 (1.38)	1.71 (0.23)
6	7 (1.26)	6 (1.28)	7 (1.34)	5 (0.52)	5 (2.12)	6 (1.37)	7 (0.50)	7 (1.53)	6.25 (1.24)	0.79 (0.28)
7	7 (0.83)	7 (0.84)	7 (0.99)	5 (1.00)	5 (1.06)	5 (1.10)	7 (0.86)	8 (0.94)	6.38 (0.95)	1.41 (0.01)
8	8 (0.96)	4 (1.45)	6 (0.80)	7 (1.07)	5 (1.52)	9 (0.90)	10 (1.03)	10 (0.88)	7.38 (1.08)	5.12 (0.07)
9	5 (1.04)	8 (0.82)	6 (0.38)	7 (0.86)	6 (0.87)	8 (0.71)	9 (0.97)	10 (0.65)	7.38 (0.79)	2.84 (0.04)
10	9 (0.94)	7 (1.17)	7 (1.10)	6 (1.33)	6 (0.87)	10 (0.68)	10 (1.03)	6 (0.87)	7.62 (1.00)	3.12 (0.04)
Reference (R) station										
11	5 (0.46)	2 (1.20)	2 (1.45)	3 (0.93)	1 (0.50)	2 (1.35)	3 (0.53)	2 (1.30)	2.50 (0.96)	1.43 (0.17)
12	10 (0.97)	10 (1.05)	6 (1.28)	8 (0.80)	5 (1.20)	10 (1.42)	9 (1.03)	5 (1.42)	7.88 (1.15)	4.98 (0.05)

2. Cochran's (C) test for homogeneity of variances of midge data

$$C_{(cal.)} = s^2\,(max.) / s^2\,(total)$$

Survival data[c]

$C_{(cal.)}$ = 8.00 / 34.61 = 0.23 *,
as compared to $C_{(tab.)}$ =
0.22 for P = 0.05, k = 13,
and v = 7

Weight data[c]

$C_{(cal.)}$ = 0.28 / 1.24 = 0.23 *,
as compared to $C_{(tab.)}$ =
0.22 for P = 0.05, k = 13,
and v = 7

3. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of midge survival (probabilities only approximate)[d,e]

Source of variation in survival	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	368.54	30.71	11.55 **
Error (R)	s (r - 1) = 91	242.38	2.66	
Total (T)	sr - 1 = 103	610.91		

as compared to $F_{(tab.)}$ = 2.42 for P = 0.01, 12 numerator df, and 91 denominator df

Sediment source (S):	R 11	PI 5	PI 4	PI 6	PI 7	PI 1
Mean ($\bar{x}$) number of survivors:	2.50	3.50	6.00	6.25	6.38	6.63

Sediment source (S):	PI 2	PI 8	PI 9	PI 10	R 12	Control	PI 3
Mean ($\bar{x}$) number of survivors:	7.38	7.38	7.38	7.62	7.88	8.63	9.88

$w_{(P = 0.05)}$ = q (square root of error MS / r)
= 4.83 (square root of 2.66 / 8)
= 0.98

Table 6.__Continued

4. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of midge weight (probabilities only approximate)[d,e]

Source of variation in weight	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	7.98	0.66	6.60 **
Error (R)	s (r - 1) = 91	8.74	0.10	
Total (T)	sr - 1 = 103	16.72		

as compared to $F_{(tab.)}$ = 2.42 for P = 0.01, 12 numerator df, and 91 denominator df

Sediment source (S):	PI 3	PI 9	PI 2	PI 1	PI 7	R 11
Mean (x) ash-free weight (mg, dry):	0.69	0.79	0.83	0.91	0.95	0.96

Sediment source (S):	PI 10	PI 8	R 12	PI 4	PI 6	PI 5	Control
Mean (x) ash-free weight (mg, dry):	1.00	1.08	1.15	1.21	1.24	1.38	1.79

$w_{(P = 0.05)}$ = q (square root of error MS / r)
= 4.83 (square root of 0.10 / 8)
= 0.19

[a]Surface sediment (down to a depth of about 15 cm) employed in midge toxicity tests was collected with a Ekman grab sampler on September 20 - 21, 2004. Laboratory control sediment consisted of clean sand, decaying leaves, and potting soil. Tests were conducted during the period of November 30 - December 10, 2004.

[b]Each replicate (r) of a sediment source (S) consisted of 10 midges at start of test (i. e., 10 midges at end of test = 100% survival).

[c]Cochran's (C) test for midge survival and weight data indicated slight heterogeneity of variances (as indicated by the symbol " * " for $C_{(cal.)}$). Nevertheless, further statistical tests were conducted with data by parametric protocols with the understanding that "P" (the level of statistical significance) may not be exactly as indicated.

[d]Parametric ANOVAs applied to midge survival and weight data documented the presence of statistically significant differences (as indicated by the symbol " ** " for $F_{(cal.)}$). The specific causes of these significant differencences were determined by Tukey's (w) test. In Tukey's test, data underscored by the same horizontal line are not significantly different, whereas data not underscored by the same horizontal line are significantly different.

[e]Sediment from potentially impacted (PI) sampling stations was not determined to be more toxic from a statistical perspective than sediment from Reference Station 11 (with the exception of weight of midges at PI Station 3). Consequently, sediment from all PI sampling stations (and the reference stations) was further evaluated in "Phase III" chronic toxicity tests with amphipods (*Hyalella azteca*).

Table 7.__Statistical analysis of survival, growth (weight), and reproduction of amphipods (*Hyalella azteca*) exposed for up to 42 days to laboratory control sediment and surface sediment from study area (Phase III toxicity tests)[a, b]

A. 28-Day Exposure

1. Number of surviving amphipods (weight: mg, dry wt)[c, d]

Sediment source (S)	Replicate – r: 1	2	3	4	5	6	7	8	9	10	11	12	Mean ($\bar{x}$)	Variance (s^2)
Control	10 (0.35)	10 (0.49)	10 (0.36)	10 (0.46)	10	10	10	10	10	10	10	10	10.00 (0.415)	0 (0.0050)
Potentially impacted (PI) stations														
1	4 (0.22)	4 (0.17)	5 (0.14)	4 (0.15)	7	2	6	1	5	3	4	6	4.25 (0.170)	2.93 (0.0013))
2	1 (0.40)	1 (0.30)	4 (0.23)	1 (0.20)	2	3	3	4	3	3	10	1	3.00 (0.282)	6.18 (0.0079))
3	4 (0.12)	6 (0.13)	0 (0)	7 (0.16)	4	6	5	7	5	8	6	9	5.58 (0.102)	5.36 (0.0050))
4	8 (0.21)	8 (0.19)	8 (0.19)	9 (0.23)	10	9	7	8	10	7	7	6	8.08 (0.205)	1.54 (0.0004))
5	8 (0.30)	10 (0.37)	10 (0.31)	10 (0.27)	9	9	9	10	9	10	9	10	9.42 (0.312)	0.45 (0.0018)
6	8 (0.35)	10 (0.47)	10 (0.46)	10 (0.68)	9	10	10	10	10	8	10	10	9.58 (0.490)	0.63 (0.0190)
7	0 (0)	1 (0.10)	0 (0)	0 (0)	4	5	2	10	0	0	3	1	2.17 (0.025)	9.06 (0.0025)
8	0 (0)	0 (0)	0 (0)	1 (0.10)	0	10	1	7	0	2	2	10	2.75 (0.025)	15.30 (0.0025)
9	10 (0.32)	8 (0.27)	8 (0.32)	9 (0.37)	10	10	10	10	8	10	8	8	9.08 (0.320)	0.99 (0.0017)
10	6 (0.30)	7 (0.29)	7 (0.24)	5 (0.30)	8	10	10	5	10	10	6	10	7.83 (0.282)	4.33 (0.0008)
Reference (R) stations														
11	7 (0.24)	8 (0.20)	6 (0.37)	7 (0.21)	6	6	5	2	6	6	4	4	5.58 (0.255)	2.63 (0.0062)
12	4 (0.28)	4 (0.30)	3 (0.37)	10 (0.24)	5	6	7	3	5	7	8	9	5.92 (0.298)	5.36 (0.0030)

2. Cochran's (C) test for homogeneity of variances of amphipod data

$$C_{(cal.)} = s^2\ (max.) / s^2\ (total)$$

Survival data[e]

$C_{(cal.)} = 15.30 / 54.76 = 0.28$ *,
as compared to $C_{(tab.)} =$ 0.19 for $P = 0.05$, $k = 13$, and $v = 11$

Weight data[e]

$C_{(cal.)} = 0.0190 / 0.0571 = 0.33$ *,
as compared to $C_{(tab.)} =$ 0.31 for $P = 0.05$, $k = 13$, and $v = 3$

3. Nonparametric " t " tests of amphipod survival (comparison of R 11 reference station to Potentially Impacted (PI) Stations with lower mean survival)[f]

Comparison (mean survival) R 11 (5.58) vs.	$t_{(cal.)}$	$t_{(tab.)}$ (one-tailed test)
1) PI 1 (4.25)	1.98 *	1.72 for P = 0.05 and 22 df
2) PI 2 (3.00)	3.01 **	2.54 for P = 0.01 and 19 df
3) PI 7 (2.17)	3.46 **	2.57 for P = 0.01 and 17 df
4) PI 8 (2.75)	2.32 *	1.75 for P = 0.05 and 15 df

4. Nonparametric " t " tests of amphipod weight (comparison of R 11 reference station to Potentially Impacted (PI) Stations with lower mean weight)[f]

Comparison (mean weight, mg) R 11 (0.255) vs.	$t_{(cal.)}$	$t_{(tab.)}$ (one-tailed test)
1) PI 1 (0.170)	1.97 ns	2.13 for P = 0.05 and 4 df
2) PI 3 (0.102)	2.89 *	1.94 for P = 0.05 and 6 df
3) PI 4 (0.205)	1.24 ns	2.35 for P = 0.05 and 3 df
4) PI 7 (0.025)	4.94 **	3.36 for P = 0.01 and 5 df
5) PI 8 (0.025)	4.94 **	3.36 for P = 0.01 and 5 df

B. 42-Day Exposure

1. Number of surviving amphipods (weight: mg, dry wt)[c, g]

Sediment source (S)	Replicate – r 1	2	3	4	5	6	7	8	9	10	11	12	Mean ($\bar{x}$)	Variance (s^2)
Control	—	—	—	—	6 (0.18)	8 (0.44)	5 (0.18)	2 (0.20)	6 (0.28)	6 (0.33)	7 (0.30)	2 (0.15)	5.25 (0.255)	4.79 (0.010)
Potentially impacted (PI) stations														
1	—	—	—	—	2 (0.15)	0 (–)	3 (0.37)	0 (–)	4 (0.18)	0 (–)	1 (0.10)	1 (0.30)	1.38 (0.220)	2.27 (0.012)
2	—	—	—	—	2 (0.15)	2 (0.15)	3 (0.13)	0 (–)	3 (0.13)	2 (0.50)	4 (0.30)	1(0.30)	2.12 (0.237)	1.55 (0.019)
3	—	—	—	—	1 (0.20)	5 (0.24)	2 (0.30)	3 (0.23)	1 (0.30)	3 (0.23)	3 (0.33)	3 (0.27)	2.62 (0.262)	1.70 (0.002)
4	—	—	—	—	7 (0.20)	4 (0.38)	2 (0.20)	5 (0.20)	4 (0.30)	5 (0.28)	6 (0.22)	2 (0.20)	4.38 (0.248)	3.12 (0.004)
5	—	—	—	—	7 (0.33)	9 (0.29)	5 (0.42)	9 (0.22)	8 (0.31)	10 (0.33	6 (0.42)	7 (0.20)	7.62 (0.315)	2.84 (0.006)
6	—	—	—	—	9 (0.47)	10 (0.30	10 (0.35	9 (0.28)	9 (0.36)	8 (0.31)	10 (0.39	7 (0.31)	9.00 (0.346)	1.14 (0.004)
7	—	—	—	—	3 (0.23)	5 (0.18)	1 (0.30)	8 (0.24)	0 (–)	0 (–)	1 (0.10)	1 (0.20)	2.38 (0.208)	7.98 (0.004)
8	—	—	—	—	0 (–)	4 (0.08)	1 (0.20)	3 (0.10)	0 (–)	2 (0.15)	1 (0.20)	8 (0.12)	2.38 (0.142)	7.12 (0.003)
9	—	—	—	—	9 (0.32)	10 (0.41	8 (0.49)	6 (0.38)	6 (0.37)	8 (0.39)	7 (0.37)	6 (0.27)	7.50 (0.375)	2.29 (0.004)
10	—	—	—	—	3 (0.30)	6 (0.28)	4 (0.27)	2 (0.35)	2 (0.40)	2 (0.25)	4 (0.23)	9 (0.26)	4.00 (0.292)	6.00 (0.003)
Reference (R) stations														
11	—	—	—	—	3 (0.30)	0 (–)	0 (–)	0 (–)	4 (0.20)	3 (0.23)	0 (–)	0 (–)	1.25 (0.243)	3.07 (0.003)
12	—	—	—	—	0 (–)	3 (0.43)	1 (0.20)	2 (0.45)	2 (0.60)	6 (0.33)	8 (0.25)	4 (0.20)	3.25 (0.351)	7.07 (0.022)

2. Cochran's (C) test for homogeneity of variances of amphipod data

$$C_{(cal.)} = s^2\,(max.) / s^2\,(total)$$

Survival data[e]

$C_{(cal.)}$ = 7.98 / 50.94 = 0.16 ns,

as compared to $C_{(tab.)}$ = 0.22 for P = 0.05, k = 13, and v = 7

Weight data[e]

$C_{(cal.)}$ = 0.022 / 0.096 = 0.23 ns,

as compared to $C_{(tab.)}$ = ~0.23 for P = 0.05, k = 13, and v = ~6

3. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of amphipod survival[h]

Source of variation in survival	Degrees of freedom (df)	Sum of Squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	621.60	51.80	13.21 **
Error (E)	s(r - 1) = 91	356.62	3.92	
Total (T)	sr - 1 = 103	978.22		

as compared to F(tab.) = 2.42 for P = 0.01, 12 numerator df, and 91 demominator df

Sediment source (S):	R 11	PI 1	PI 2	PI 7	PI 8	PI 3	R 12
Mean (x) number of survivors:	1.25	1.38	2.12	2.38	2.38	2.62	3.25

Sediment source (S):	PI 10	PI 4	Control	PI 9	PI 5	PI 6
Mean (x) number of survivors:	4.00	4.38	5.25	7.50	7.62	9.00

$w_{(P = 0.05)}$ = q (square root of error MS / r)
= 4.63 (square root of 3.92 / 8)
= 1.20

Table 7.__Continued

B. 42-Day Exposure (Continued)

4. Parametric one-way analysis of variance (ANOVA) followed by Tukey's (w) test of amphipod weight[h]

Source of variation in weight	Degrees of freedom (df)	Sum of Squares (SS)	Mean square (MS)	$F_{(cal.)}$
Sediment source (S)	s - 1 = 12	0.349	0.029	3.62 **
Error (E)	s(r - 1) = 77	0.579	0.008	
Total (T)	sr - 1 = 89	0.928		

as compared to F(tab.) = 2.46 for P = 0.01, 12 numerator df, and 77 demominator df

Sediment source (S):	PI 8	PI 7	PI 1	PI 2	R 11	PI 4	Control
Mean (x) weight:	0.142	0.208	0.220	0.237	0.243	0.248	0.255

Sediment source (S):	PI 3	PI 10	PI 5	PI 6	R 12	PI 9
Mean (x) weight:	0.262	0.292	0.315	0.346	0.351	0.375

$w_{(P = 0.05)}$ = q (square root of error MS / r)
= 4.85 (square root of 0.008 / ~7)
= 0.062

[a]Surface sediment (down to a depth of about 15 cm) employed in amphipod toxicity tests was collected with an Ekman grab sampler on September 20 - 21, 2004. Laboratory control sediment consisted of clean sand, decaying leaves, and potting soil. Tests were conducted during the period of February 24 - April 6, 2005.

[b]Number of young produced per female amphipod at Days 35 and 42 of exposure ranged fom 0 to 6 for the control, 0 to 15 for Potentially Impacted (PI) stations, and 0 to 3 for Reference (R) stations. Young amphipods were never produced at Reference Station 11.

[c]Each replicate (r) of a sediment source (S) consisted of 10 amphipods at start of test (i. e., 10 amphipods at end of test = 100% survival) .

[d]Weight of amphipods was evaluated in just Replicates 1 - 4 of the 28-day exposure.

[e]Cochran's (C) test for amphipod survival and weight indicates homogeneity of variances when identified by the symbol "ns" for $C_{[cal.]}$, thereby justifying further statistical testing by parametric protocols. Heteroscedasticity is indicated by the symbol " * " for $C_{[cal.]}$, thereby requiring further statistical tests to be conducted by nonparametric protocols.

[f]Nonparametric " t " tests applied to 28-day amphipod survival and weight data documented the absence of statistically significant differences between data as indicated by the symbol " ns " for $t_{[cal.]}$ and the presence of statistically significant differences between data as indicated by the symbol " * " or " ** " for $t_{[cal.]}$.

[g]Survival and weight of amphipods was evaluated in just Replicates 5 - 12 of the 42-day exposure.

[h]Parametric ANOVAs applied to 42-day amphipod survival and weight data documented the presence of statistically significant differences among data (as indicated by the symbol " ** " for $F_{[cal.]}$). The specific causes of these significant differences were determined by Tukey's (w) test. In Tukey's test, data underscored by the same horizontal line are not significantly different, whereas data not underscored by the same horizontal line are significantly different.

amphipods exposed to sediment for 42 days (Table 7) and concentration of lead in sediment (Table 3) is 8%, which is the amount of variation in weight of organisms can be explained in terms of variation in lead concentration of sediment.

4. WILDLIFE FOOD-WEB MODELS

This part of the report consists of two sections addressing food-web models for the belted kingfisher and mink exposed to lead.

Both food-web models result in derivation of a hazard quotient (HQ) which is defined as:

$$HQ = EEE / TRV, \qquad \text{(Equation 1)}$$

with EEE = estimated environmental exposure, and TRV = toxicity reference value, with both values expressed in terms of the amount of lead ingested during a day normalized to the body weight (BW) of the wildlife (i. e., mg [Pb]/ kg BW/ day). HQs greater than unity (1) are sometimes considered to be suggestive of potential hazard to wildlife.

All assumptions and calculations employed in the food-web models are presented in the Hazard Quotient Worksheets contained in Appendix B of this report. It is important to note here that EEEs in the models are based on chemical data previously presented for surface water (Table 1), surface sediment (Table 2), and, most importantly, assumed prey of wildlife (Table 3). In addition, assumptions pertaining to BWs of wildlife, prey (food) ingestion rates, and water ingestion rates are predicated on life-history information developed by EPA (U. S. EPA, 1993). Sediment ingestion rates are based on information provided by Beyer et al. (1994).

Both food-web models conservatively employ unity (1) for time-use factors (TUFs) and area-use factors (AUFs).

4.1 Belted Kingfisher

The food-web model for the belted kingfisher generated the following HQs for selected water segments in the study area (Table 8): 7.5 (upstream stretch of West Stream); 1.0 (ponded area south of COE channel); 1.4 (COE channel); and 1.0 (West Stream and Oldmans Creek reference areas).

Water was an inconsequential contributor of lead in the belted kingfisher model. Prey of the kingfisher constituted approximately 29 to 35% of EEE of lead at potentially impacted areas; while sediment was dominant, constituting about 64 to 71% of modeled exposure of the kingfisher to lead. If just prey was evaluated in the kingfisher model, HQs for potentially impacted areas would be: 2.5 (upstream stretch of West Stream); 0.29 (ponded area south of COE channel); and 0.48 (COE channel).

4.2 Mink

The food-web model for the mink generated HQs of (Table 8): 17 (upstream stretch of West Stream); 2.3 (ponded area south of COE channel); 3.1 (COE channel); and 2.2 (West Stream and Oldmans Creek reference areas).

As in the case for the belted kingfisher, water was an inconsequential contributor of lead in the mink model; and prey and sediment contributed the same relative percentages of lead exposure to the mink as described above for the kingfisher. If just prey was evaluated in the mink model, HQs for potentially impacted areas would be: 5.6 (upstream stretch of West Stream); 0.65 (ponded area south of COE channel); and 1.1 (COE channel).

Table 8.__Hazard quotients (HQs) for selected wildlife potentially exposed to lead in study area[a]

Location in study area	Estimated environmental exposure -- EEE (mg/kg BW/day)	Toxicity reference value --TRV (mg/kg BW/day)	Hazard quotient -- HQ (EEE / TRV)
Belted Kingfisher (*Megaceryle alcyon*)			
Upstream stretch of West Stream	2.1	0.28	7.5
Ponded area south of COE channel	0.28	0.28	1.0
COE channel	0.39	0.28	1.4
Reference areas (West Stream and Oldmans Creek)	0.28	0.28	1.0
Mink (*Mustela vison*)			
Upstream stretch of West Stream	0.55	0.032	17
Ponded area south of COE channel	0.073	0.032	2.3
COE channel	0.10	0.032	3.1
Reference areas (West Stream and Oldmans Creek)	0.072	0.032	2.2

[a]Details of HQ calculations are presented in Appendix B.

5. TIME-SERIES COMPARISONS OF ENVIRONMENTAL CHARACTERISTICS OF SITE

The mean concentration of lead in surface sediment at potentially impacted sampling stations (Table 9) decreased from 379 mg/kg (dry wt) in 2000 to 296 mg/kg in 2004 (a 22% decrease).

Body burdens of lead in aquatic life collected from potentially impacted stations decreased from a mean value of 1.8 mg/kg (wet wt) in 2000 to <0.63 mg/kg in 2004. (Annual comparisons of body burdens of lead in biota are confounded by the different species captured in different years.)

The macrobenthos community at potentially impacted stations (as judged by the Lloyd-Ghelardi Equitability Index) remained relatively constant over the years ("e" = 0.52 – 0.66).

Phase I toxicity tests (evaluation of acute toxicity of sediment to amphipods) identified 70% of sediments (stations) to be toxic in 2000, while 0% were so identified in 2004. Phase II testing (assessment of acute toxicity of sediment to midges) demonstrated a reduction in toxicity from 67% to 10% during the 4-year period. Finally, Phase III toxicity testing (evaluation of chronic toxicity of sediment to amphipods) documented just a single station in 2004 that was associated with toxicity at the end of the 42-day testing period.

Finally, modeled HQs for lead in both the belted kingfisher and mink continued on a downward trend in 2004. However, as previously discussed, these HQ values are primarily a function of concentration of lead in sediment and are also influenced by the particular species of aquatic life collected during a specific year.

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Table 9.__Comparisons of environmental characteristics of study area during pre-remediation study in 2000 vs. post-remediation studies in 2002, 2003, and 2004 (this study)[a]

	Potentially impacted sampling stations										
	Upstream stretch of West Stream				Ponded area south of COE channel	COE Channel					Mean
Year	1	2	3	4	5	6	7	8	9	10	value
Lead in Surface Sediment (mg/kg, dry wt))											
2000	300	690	1,100	250	240	310	170	330	280	120	379
2002	600	100	110	320	630	250	180	200	90	49	253
2003	270	590	85	840	360	130	69	22	90	50	251
2004	1,400	860	180	190	73	31	98	20	81	27	296
Body Burden of Lead in Aquatic Life (mean values; mg/kg, wt wt)											
2000	3.8	0.41	–	3.5	1.0	–	–	–	–	0.43	1.8
2002	5.5	17	<1.8	<1.7	–	–	<1.5	–	<1.7	<1.6	<4.4
2003	1.0	0.84	1.5	0.16	0.62	0.29	0.27	0.28	–	<0.12	<0.56
2004	–	2.2	1.2	0.72	0.16	0.42	<0.31	0.34	0.21	0.13	<0.63
Macrobenthos Community (Lloyd-Ghelardi Equitability Index)											
2000	0.73	0.31	0.67	0.62	0.83	0.55	0.46	1.14	0.44	0.80	0.66
2002	0.89	0.71	0.99	0.83	0.69	0.39	0.24	0.26	0.22	0.27	0.55
2003	0.59	1.29	0.45	0.40	0.46	0.51	0.57	–	0.47	0.58	0.59
2004	1.12	0.95	0.24	0.49	0.40	0.54	0.22	0.41	0.35	0.50	0.52
Toxicity Demonstrated in Acute Amphipod (*Hyalella azteca*) Tests (Phase I Tests)											
2000	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	70% toxic
2002	No	Yes	No	No	No	No	No	No	No	No	10% toxic
2003	No	No	No	No	Yes	No	No	No	No	No	10% toxic
2004	No	No	No	No	No	No	No	No	No	No	0% toxic
Toxicity Demonstrated in Acute Midge (*Chironomus tentans*) Tests (Phase II Tests)											
2000	No	–	Yes	–	–	–	Yes	–	–	–	67% toxic
2002	Yes	–	Yes	Yes	No	Yes	Yes	Yes	Yes	No	78% toxic
2003	Yes	Yes	No	Yes	–	Yes	Yes	No	Yes	Yes	78% toxic
2004	No	No	Yes	No	No	No	No	No	No	No	10% toxic
Toxicity Demonstrated in Chronic Amphipod (*Hyalella azteca*) Tests (Phase III Tests)											
2000	Yes	–	–	–	–	–	–	–	–	–	100% toxic
2002	–	–	–	–	No	–	–	–	–	No	0% toxic
2003	–	–	No	–	–	–	–	No	–	–	0% toxic
2004	No	No	No	No	No	No	No	Yes	No	No	10% toxic
Hazard Quotients for Belted Kingfisher (*Megaceryle alcyon*)											
2000	11				5.7	2.4					6.4
2002	17				–	2.7					9.8
2003	8.2				3.5	1.6					4.4
2004	7.5				1.0	1.4					3.3
Hazard Quotients for Mink (*Mustela vison*)											
2000	25				13	5.6					15
2002	38				–	6.2					22
2003	18				8.1	3.8					10
2004	17				2.3	3.1					7.5

[a]Data presented in this table are abstracted from comparable tables in the pre-remediation report (CDR Environmental Specialists, 2001) and subsequent post-remediation monitoring reports (CDR Environmental Specialists; 2003, 2004, and this report). Changes in environmental characteristics between 2000 and 2004 cannot be interpreteted as being statistically significant and are presented in this report only to satisfy an obvious objective of the overall investigation of the site.

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$^{C}D_{R}$ Appendix

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2

Figure 1.__ Photographs of sampling stations in study area

3

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Figure 1.__ Photographs of sampling stations in study area (Continued)

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Figure 1.__ Photographs of sampling stations in study area (Continued)

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Figure 1.__ Photographs of sampling stations in study area (Continued)

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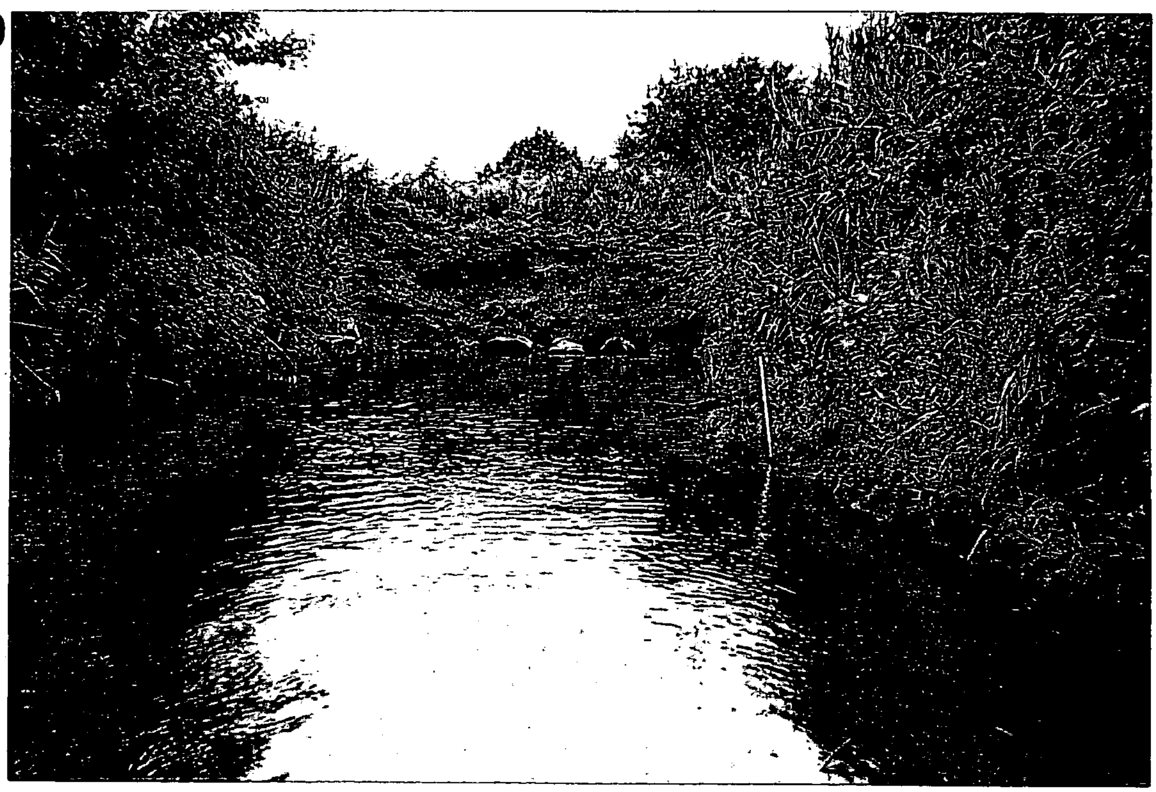

Figure 1.__ Photographs of sampling stations in study area (Continued)

R11

R12

Figure 1.__ Photographs of sampling stations in study area (Continued)

CDR Appendix

Appendix B

Hazard Quotient Worksheets For Study Area

B.1__HAZARD QUOTIENT WORKSHEET FOR BELTED KINGFISHER (*MEGACERYLE ALCYON*) EXPOSED TO LEAD IN STUDY AREA

A. Estimated Environmental Exposures (EEEs)

A.1 Basic Exposure Assumptions

A.1.1 Body weight (BW): 0.15 kg (wet wt)

A.1.2 Prey (food) ingestion rate (PIR): 0.075 kg/day (wet wt) – 50% of body weight/day

A.1.3 Prey (food) items(PI): aquatic life (fishes, and crayfish) collected at specific sampling stations in study area

A.1.4 Sediment ingestion rate (SIR): 0.0015 kg/day (wet wt) – 2% of food ingestion rate

A.1.5 Water ingestion rate (WIR): 0.016 L/day

A.1.6 Time-use factor (TUF): 1 (year-long resident)

A.1.7 Area-use factor (AUF): 1 (assuming open water in winter)

A.2 Exposure Equation

$$\text{EEE (mg/kg BW/day)} = \frac{[(CP \times PIR) + (CS \times SIR) + (CW \times WIR)]\,[TUF]\,[AUF]}{BW},$$

with CP = lead concentration in prey (wet wt); CS = lead concentration in sediment (wet wt); and CW = lead (total lead) concentration in water.

A.3 Selected Exposure Scenarios and Results

A.3.1 Upstream Stretch of West Stream (Data from Sampling Stations 1, 2, 3, and 4 considered collectively)

– CP = 1.4 mg/kg (mean of 9 body burden values for the four stations; Table 3 in main body of report)
– CS = 140 mg/kg (mean of 4 sediment values for the four stations; Table 2 in main body of report)
– CW = 0.021 mg/L (mean of 4 water values for the four stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 2.1 mg/kg BW/day

A.3.2 Ponded Area South of COE Channel (Data from Sampling Station 5)

– CP = 0.16 mg/kg (mean of 2 body burden values for the station; Table 3 in main body of report)
– CS = 20 mg/kg (1 sediment value for the station; Table 2 in main body of report)
– CW = 0.0025 mg/L (1 water value for the station; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.28 mg/kg BW/day

A.3.3 COE Channel (Data from Sampling Stations 6, 7, 8, 9, and 10 considered collectively)

– CP = 0.27 mg/kg (mean of 13 body burden values for four stations; Table 3 in main body of report; non-detected values assigned 1/2 of detection limits)
– CS = 25 mg/kg (mean of 5 sediment values for the five stations; Table 2 in main body of report)
– CW = 0.0025 mg/L (mean of 5 water values for the five stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.39 mg/kg BW/day

A.3.4 Reference Areas (Data from Sampling Stations 11 and 12 considered collectively)

– CP = 0.21 mg/kg (mean of 4 body burden values for the two stations; Table 3 in main body of report)
– CS = 17 mg/kg (mean of 2 sediment values for the two stations; Table 2 in main body of report)
– CW = 0.0025 mg/L (mean of 2 water values for the two stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.28 mg/kg BW/day

B.1 HAZARD QUOTIENT WORKSHEET FOR BELTED KINGFISHER (*MEGACERYLE ALCYON*) EXPOSED TO LEAD IN STUDY AREA – CONTINUED

B. Toxicity Reference Value (TRV)

TRV based on 11-day study (Osborn et al., 1983) of survival and various sublethal effects of European starlings (*Sturnus vulgaris*) exposed to triethyllead chloride and trimethyllead chloride via oral administration (capsules)

No-observed-adverse-effect-level (NOAEL) in study = 2.8 mg/kg BW/day

TRV = 0.28 mg/kg BW/day (NOAEL / 10 (subchronic-to-chronic correction factor)

C. Hazard Quotients (HQs)

C.1 Hazard Quotient (HQ) Equation

HQ = EEE (mg/kg BW/day) / TRV (mg/kg BW/day)

C.2 Hazard Quotient (HQ) Results

– Upstream Stretch of West Stream: 2.1 / 0.28 = 7.5

– Ponded Area South of COE Channel: 0.28 / 0.28 = 1.0

– COE Channel: 0.39 / 0.28 = 1.4

– Reference Areas: 0.28 / 0.28 = 1.0

B.2__HAZARD QUOTIENT WORKSHEET FOR MINK (*MUSTELA VISON*) EXPOSED TO LEAD IN STUDY AREA

A. Estimated Environmental Exposures (EEEs)

A.1 Basic Exposure Assumptions

A.1.1 Body weight (BW): 1 kg (wet wt)

A.1.2 Prey (food) ingestion rate (PIR): 0.13 kg/day (wet wt) – 13% of body weight/day

A.1.3 Prey (food) items(PI): aquatic life (fish, frogs, and/or crayfish) collected at specific sampling stations in study area

A.1.4 Sediment ingestion rate (SIR): 0.0026 kg/day (wet wt) – 2% of food ingestion rate

A.1.5 Water ingestion rate (WIR): 0.028 L/day

A.1.6 Time-use factor (TUF): 1 (year-long resident)

A.1.7 Area-use factor (AUF): 1 (range may approximate between 1.0 - 5.0 km of stream length)

A.2 Exposure Equation

$$\text{EEE (mg/kg BW/day)} = \frac{[(CP \times PIR) + (CS \times SIR) + (CW \times WIR)]\,[TUF]\,[AUF]}{BW},$$

with CP = lead concentration in prey (wet wt); CS = lead concentration in sediment (wet wt); and CW = lead concentration in water.

A.3 Selected Exposure Scenarios and Results

A.3.1 Upstream Stretch of West Stream (Data from Sampling Stations 1, 2, 3, and 4 considered collectively)

– CP = 1.4 mg/kg (mean of 9 body burden values for the four stations; Table 3 in main body of report)
– CS = 140 mg/kg (mean of 4 sediment values for the four stations; Table 2 in main body of report)
– CW = 0.021 mg/L (mean of 4 water values for the four stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.55 mg/kg BW/day

A.3.2 Ponded Area South of COE Channel (Data from Sampling Station 5)

– CP = 0.16 mg/kg (mean of 2 body burden values for the station; Table 3 in main body of report)
– CS = 20 mg/kg (1 sediment value for the station; Table 2 in main body of report)
– CW = 0.0025 mg/L (1 water value for the station; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.073 mg/kg BW/day

A.3.3 COE Channel (Data from Sampling Stations 6, 7, 8, 9, and 10 considered collectively)

– CP = 0.27 mg/kg (mean of 13 body burden values for four stations; Table 3 in main body of report; non-detected values assigned 1/2 of detection limits)
– CS = 25 mg/kg (mean of 5 sediment values for the five stations; Table 2 in main body of report)
– CW = 0.0025 mg/L (mean of 5 water values for the five stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.10 mg/kg BW/day

A.3.4 Reference Areas (Data from Sampling Stations 11 and 12 considered collectively)

– CP = 0.21 mg/kg (mean of 4 body burden values for the two stations; Table 3 in main body of report)
– CS = 17 mg/kg (mean of 2 sediment values for the two stations; Table 2 in main body of report)
– CW = 0.0025 mg/L (mean of 2 water values for the two stations; Table 1 in main body of report; non-detected values assigned 1/2 of detection limits)

EEE = 0.072 mg/kg BW/day

B. Toxicity Reference Value (TRV)

TRV based on chronic study (Demayo et al., 1982) with dogs (*Canis familiaris*)

Lowest-observed-adverse-effect-level (LOAEL) in study = 0.32 mg/kg BW/day

TRV = 0.032 mg/kg BW/day (LOAEL / 10 (LOAEL-to-NOAEL correction factor)

C. Hazard Quotients (HQs)

C.1 Hazard Quotient (HQ) Equation

HQ = EEE (mg/kg BW/day) / TRV (mg/kg BW/day)

C.2 Hazard Quotient (HQ) Results

- Upstream Stretch of West Stream: 0.55 / 0.032 = 17
- Ponded Area South of COE Channel: 0.073 / 0.032 = 2.3
- COE Channel: 0.10 / 0.032 = 3.1
- Reference Areas: 0.072 / 0.032 = 2.2